

ished and dwellings unroofed or otherwise damaged, numerous windmills and hay-stacks were blown down. Some cattle were killed by falling buildings. The storm was quite severe at De Kalb, the telegraph wires were down and communication was cut off for several hours. A large building was struck by lightning and consumed, loss \$20,000.

Detroit, Michigan: a thunder-storm began at 12.05 a. m. of the 19th. Heavy rain fell between 12.20 and 11 a. m. No damage was done by this storm although the wind for a few minutes blew at the rate of sixty miles per hour from the north. Direction of wind before the storm, southeast; during the storm, north; after, southwest. A westerly gale set in at midday attaining a velocity of twenty-nine miles per hour.

Buffalo, New York: the morning of the 19th opened with heavy rain, the weather continued rainy until the afternoon. Cautionary signals were hoisted at 10.55 a. m. A severe gale from the southwest began at 2 p. m., reaching at 3.55 p. m. a velocity of forty-four miles per hour. The water in the lake was very rough, completely submerging the outer breakwater. No vessel left port during the display of cautionary signals; a number, that left before the warning was given were compelled to return, several of them in a disabled condition. In the country about Buffalo many barns were unroofed, while fences, hay-ricks, and fruit trees were thrown down by the gale. Country roads were rendered almost impassable by the heavy rain, which fell continuously during the day.

Oswego, New York: a heavy thunder-storm and high wind occurred on the afternoon of the 19th. The rainfall was heavy between 5 and 5.20 p. m. From 6.50 to 7.15 p. m. the wind blew from the west at the rate of thirty-two miles per hour. A few shade trees were blown down in the city, and considerable fruit destroyed in the country by being blown from the trees.

Sandusky, Ohio: on the 19th a gale began at 1.43 a. m. and ended at 2.45 a. m., began again at 9 a. m. and ended at 6.15 p. m.; maximum velocity, thirty-four miles per hour from the northwest, at 2.05 p. m. Heavy rain, accompanied by thunder and lightning, set in at 1.40 a. m.

Alden Station, Luzerne county, Pennsylvania: this town was visited by a heavy wind and rain storm on the night of the 19-20th. Nearly every building in the town was damaged; several small buildings were completely destroyed. A hotel and a public school building were partially destroyed, and several persons injured.

Wellsborough, Tioga county, Pennsylvania: on the 19th a tornado occurred in Tioga county near Knoxville. The storm destroyed several barns and houses and blew down forest trees. Its track extended over a distance of ten miles. Heavy thunder-storms and high winds were general throughout eastern Pennsylvania on the afternoon of the 19th. At Alden several miners' houses were blown down, and many other buildings unroofed. Farmers suffered considerable loss, the wind unroofing barns and destroying unripe fruit.

Decatur, Indiana: on the afternoon of the 22d a violent wind and rain storm did considerable damage in this town and vicinity. Many buildings were unroofed and small structures demolished. West of the town the storm assumed the form of a tornado and uprooted many acres of forest trees. A heavy storm also occurred on the 24th, destroying fencing and blowing down orchards. In this town much damage was done to the manufacturing interests by the unroofing of buildings. The total damage is estimated at \$50,000.

Cincinnati, Ohio: heavy rain and thunder-storm set in at 5.30 p. m. of the 23d and continued until 6.40 p. m. The storm came from the west and moved toward the southeast and was accompanied by high wind, maximum velocity thirty-two miles per hour. Reports from numerous places show that severe thunder-storms, in some places accompanied by hail and high wind, prevailed throughout the state. At Urbana, in Champaign county, several buildings were unroofed and considerable damage done to fruit and shade trees. The railroad station at Bluffton, and numerous barns in Wyandot, Seneca,

Champaign, and Allen counties were struck by lightning and burned.

Lima, Allen county, Ohio: at 7 a. m. of the 23d a heavy rain and thunder-storm set in. During the storm a large oil tank was struck by lightning and burned, together with a large building and the machinery used in refining the oil; the loss is estimated at \$25,000.

Fort Assinaboine, Montana: fair, cool weather, with brisk and high winds from the southwest and west, prevailed during the 23d. Between 3 and 4 p. m. the wind attained a velocity of forty-one miles per hour. High west winds also prevailed during the 24th and 25th; on the 25th, between 4 and 5 p. m., it blew at the rate of forty miles per hour from the southwest.

Grand Haven, Michigan: heavy rain and vivid lightning set in at 1.02 and continued until 5.05 a. m. of the 24th; amount of rainfall 2.02 inches. Telegraph and telephone lines suffered considerable damage, communication being cut off until 11 a. m. During the storm several houses in the city were struck by lightning. Reports show that the storm was severe throughout the surrounding country, several barns being struck by lightning and burned.

Fort Sill, Indian Territory: a thunder-storm began at 2 p. m. and continued until 4.30 p. m. of the 26th. The storm came from the southwest and was accompanied by heavy rain and high wind, which unroofed one of the post buildings.

#### TORNADO STUDIES FOR SEPTEMBER, 1886.

[Prepared by Lieut. JNO. P. FINLEY, Signal Corps, U. S. Army, Assistant.]

Tornadoes occurred in September on three days, the 12th, 16th, and 18th, as will be seen by reference to the accompanying table, which presents a brief history of each storm and the authority upon which the report is based.

The tornadoes occurring on the 16th were found to be the most destructive as well as the most numerous of the month. In order to invite special attention to the marked disturbances on this day, and graphically present the surrounding atmospheric conditions which were prevailing at the time, chart number vii has been prepared and will be found on the last page of this REVIEW.

Chart number vii is the 3 p. m. (Eastern time) tri-daily weather map of September 16th. The isobars are drawn for every tenth of an inch difference in pressure, and the isotherms for every difference of 10° in temperature. The words "High" and "Low," as used on the chart, indicate the centres of the regions of highest and lowest pressure, respectively. The location and direction of the progressive movement of the tornadoes are shown by the following sign,  $\times \times \times \times \longrightarrow$ , placed upon the chart, and to the southeast of the centre of lowest pressure.

The low-pressure area with which the tornadoes of the 16th were associated was one of the most remarkable depressions of the month. It first appeared in the Saskatchewan Valley, north of Montana, on the afternoon of the 13th. From this locality it moved slowly eastward along the northern boundary of the United States, with little increase in intensity, until the afternoon of the 15th when it was then central in extreme northern Minnesota. On this day a decided change took place in the character of the depression, which inaugurated the conditions of temperature, wind-force, and direction that precipitated the violent local storms of the 16th.

On the morning of the 14th, while the main area was central in Montana, a secondary depression appeared in southern Colorado, which at the expiration of twenty-four hours united with the former in developing a huge and irregular trough of low pressure extending from Lake Superior southwestward to New Mexico. This elongated area increased its major axis to the southwest and northeast, at the same time contracting the shorter axis until the trough reached from the Rio Grande to the fiftieth parallel, north of Lake Superior. The maximum condition was realized on the afternoon of the 16th, and disappeared on the following morning, when the combined depressions were central as a single area in the lower Saint Law-

rence valley. Throughout the entire length of the trough, which bore a singular resemblance to the characteristic funnel shape of the tornado cloud, with the lower end turned backwards and dragging far to the rear, the opposing northerly and southerly winds were well marked, with high temperature gradients.

It is significant to note that the southerly winds along the edge of the trough were attended by measured velocities ranging from 8 to 24 miles per hour, the highest velocities occurring at places from 140 to 230 miles to the southeast of the region of tornado centres. Velocities of from 5 to 15 miles per hour, with southeasterly winds, prevailed at all other stations to the south and east, as far as the Atlantic and Gulf coasts.

On the northern side of the trough the measured velocities, with northwesterly winds, ranged from 5 to 32 miles per hour, the highest velocities occurring northwest of the region of tornado centres, a distance of from 800 to 1,000 miles. The more rapidly the movement of air on opposite sides of the trough towards the centre, the more decided becomes the temperature gradient, and the more marked the conditions of unstable equilibrium in what may be termed the region of meeting of the opposing currents. There must be produced the state of unstable equilibrium to give rise to those conditions which finally conclude in the manifestation of the strong ascensional current and the vortex whirl.

The tornadoes of September 16th occurred in central Illinois, central and northern Indiana, and southern Michigan. Their course of progressive movement was generally from southwest to northeast. The time of formation varied considerably in the three states. In Michigan, from 11.30 a. m. to 1 p. m.; in Indiana, from 11.30 a. m. to 8.15 p. m.; in Illinois, from 11 a. m. to 4 p. m.

Most of the tornadoes appeared at an early hour in the day, between 11.30 a. m. and 1 p. m. The usual time of occurrence is from 2 to 6 p. m., as determined from the averages for many years. The cause of this rather unusual occurrence may be found in the temperature gradient and high wind-velocities that existed as early as 7 a. m., eastern time. From an examination of the tri-daily weather chart for that hour, it was found that the temperature gradient of the tornado region ranged in the extremes from  $2^{\circ}$  to  $5^{\circ}.4$  per geographical degree, the average of several measurements being  $4^{\circ}.5$ . The normal temperature gradient for the 7 a. m. (Eastern time) September charts for several years, for the tornado region, is  $1^{\circ}.47$  per geographical degree. Comparison with the normal, then, shows an extreme departure of  $3^{\circ}.93$ , that is, the temperature at 7 a. m., eastern time, was  $3^{\circ}.93$  per geographical degree above the normal as a maximum, and on the average  $3^{\circ}.03$  above. This was a notable abnormal condition, considering the circumstances of barometric pressure and wind-velocity at the time. Such conditions would seem to justify the expectation of violent local storms for the region in which they prevail.

The most violent, though not the largest number of tornadoes, occurred during the afternoon and evening of the 16th, from 4 to 8.15 p. m. These storms, as well as those which occurred at an earlier hour, have their tracks charted on the 3 p. m. (Eastern time) daily weather map, it being the nearest regular observation to the hour of their occurrence.

The temperature gradient of the tornado region for the 3 p. m. chart ranged in the extremes from  $4^{\circ}$  to  $18^{\circ}.7$  per geographical degree, the average being  $9^{\circ}.02$ . The normal temperature gradient for the 3 p. m. (Eastern time) September charts for several years for the tornado region is  $1^{\circ}.61$  per geographical degree, which, in comparison with the current temperature gradient, shows an extreme departure of  $17^{\circ}.09$ , that is, the maximum temperature gradient at 3 p. m. was  $17^{\circ}.09$  per geographical degree above the normal, and on the average  $7^{\circ}.41$  above. Although the normal temperature gradient at 3 p. m. (Eastern time) was only  $0^{\circ}.14$  per geographical degree above the normal gradient for 7 a. m. (Eastern time), yet the average departure from the normal gradient at 3 p. m. was  $4^{\circ}.38$  per geographical degree greater than at 7 a.

m., and the maximum departure at the former hour was  $13^{\circ}.16$  greater than at the latter. These are marked deficiencies after eliminating the effect of diurnal variations, and probably account for the greater severity of the storms during the afternoon and early evening.

The tornadoes of September 12th occurred near the Atlantic coast, in eastern Virginia, northeastern New Jersey, southeastern New York, and southern Connecticut. The hour of occurrence was from 6 to 8 p. m.

From an examination of the 3 p. m. (Eastern time) tri-daily weather map of this date, the barometric trough is found to extend from the mouth of the Saint Lawrence southwestward to North Carolina. The wind-velocities along the southern edge of the trough ranged from 9 to 20 miles per hour, and on the northern edge from 8 to 30 miles per hour. In the former case the most violent winds were within from 50 to 75 miles of the tornado centres, while in the latter they were distant from 300 to 500 miles.

The temperature gradient of the tornado region at 3 p. m. (Eastern time) ranged in the extremes from  $6^{\circ}.27$  to  $8^{\circ}.08$  per geographical degree, the average of the several measurements being  $7^{\circ}.40$  per geographical degree.

Compared with the normal temperature gradient of that region, as determined from the records of many years, which is found to be  $1^{\circ}.68$  per geographical degree, the maximum departure from the normal is  $6^{\circ}.40$  per geographical degree, the average being  $5^{\circ}.72$ .

The tornadoes of September 18th occurred in southern Missouri and northern Illinois, between the hours of 12 noon and 7.15 p. m.

An examination of the 3 p. m. (Eastern time) tri-daily weather map of this date reveals a narrow barometric trough, lying nearly due east and west, between Utah and Indiana. The wind-velocities along the southern edge of the trough ranged from 5 to 18 miles per hour, the highest being at stations within from 60 to 120 miles of the tornado centres.

The wind-velocities on the northern side of the trough ranged from 5 to 12 miles per hour, the highest being at stations within from 260 to 400 miles of the tornado centres.

The temperature gradient of the tornado region at 3 p. m. (Eastern time) ranged in the extremes from  $5^{\circ}.44$  to  $13^{\circ}.05$  per geographical degree. The normal temperature gradient for this region is found to be  $1^{\circ}.61$  per geographical degree. Compared with the current temperature gradient, we find that the maximum departure for the tornado region is  $11^{\circ}.44$  per geographical degree above the normal, and the average departure  $7^{\circ}.94$  above.

A recapitulation of the above facts and figures is graphically shown in the following table:

Date of storm.	Time.	Velocity of southerly winds.		Velocity of northerly winds.		Temperature gradients per geographical degree, at 3 p. m., eastern time.			
		Distance of maximum velocity from tornado centre.	Distance of maximum velocity from tornado centre.	Distance of maximum velocity from tornado centre.	Distance of maximum velocity from tornado centre.	Maximum current temperature gradient.	Mean current temperature gradient.	Normal temperature gradient.	Departure from normal.
September 12th ...	6 to 8 p. m.	Miles. 9-22	Miles. 50-75	Miles. 8-30	Miles. 300-500	8.08	7.40	1.68	5.72-6.40
September 16th ...	11 a. m. to 8.15 p. m.	Miles. 8-24	Miles. 140-230	Miles. 5-32	Miles. 800-1,000	18.07	9.02	1.61	7.41-17.09
September 18th ...	12 noon to 7.15 p. m.	Miles. 5-18	Miles. 60-120	Miles. 5-12	Miles. 260-400	13.05	9.55	1.61	7.94-11.44

A brief study is thus presented of the meteorological conditions attending the development of tornadoes on the 12th, 16th, and 18th of September. The prominence necessarily given to wind-direction, wind-velocity, temperature gradient, and the form of areas of low pressure, indicate their importance in a knowledge of the causes incident to tornado formation and the conditions which may justify their prognostication.

## Report of tornadoes for the month of September, 1886, by Lieut. J. P. Finley, Signal Corps, U. S. Army, Assistant.

Place.	Date.	Time.	Direction.	Form of cloud.	Number of persons killed.	Number of persons wounded.	Width of path.	Number and kind of animals killed.	Number and kind of buildings destroyed.	Total valuation of property destroyed.	Authority.
Ellington and near Burnside, Connecticut. <sup>a</sup>	12	7 p. m.	n. 30° e.	Basket			Feet. 160 to 330		Some buildings and trees.	\$5,000-\$20,000	Postmasters at Wethersfield and Tolland; Geo. H. Goodwin, Burnside, Connecticut; and Wm. A. Eddy, New York City.
Jersey City, New Jersey, Flushing, Brooklyn, and Long Island, New York.	12	6 p. m.	no.	Funnel		Several			Many		Geo. Quarterman, Flushing, New York.
Onancock, Virginia <sup>b</sup>	12	8 p. m.	ne.	Funnel			40 to 250		Very destructive.		B. M. Mears, Keller, F. T. Boggs, Boggs', Boggs' Wharf, and Wm. P. Bell, Accomack, Virginia.
Shelbyville, Illinois	16	11 a. m.	ne.	Funnel		2			Very destructive.		J. F. Llewellyn, Mexico, Missouri.
Seymour, Illinois <sup>c</sup>	16	4 p. m.	ne.	Funnel					No serious damage.		E. G. Conkling, Seymour, Illinois.
A few miles south of Springfield, Illinois	16	4 p. m.	ne.	Funnel					1 church, 1 livery stable, and several barns. Timbers were carried through the side of a building 300 feet away.		J. F. Llewellyn, Mexico, Missouri; J. H. Dunlap, Savoy, Illinois.
Tolono, Illinois	16	4 p. m.	ne.	Funnel							
Savoy, Illinois <sup>d</sup>	16	4 p. m.	ne.	Funnel	None	None	660			2,500	J. H. Dunlap, Savoy, Illinois.
Northwest of Hilldale and at Sylvania, Indiana. <sup>e</sup>	16	11:35 a. m. to noon.	ne.	Funnel					1 house, 2 barns, and smaller buildings.		Jesse Houchin, Hilldale, and Joseph C. Swain, postmaster, Sylvania, Indiana.
Three miles south of Covington, Indiana.	16	4 p. m.	ne.	Funnel			Narrow		Much timber and a few buildings.		C. L. Myers, Covington, Indiana.
Terre Haute, Indiana	16	11:30 a. m.	ne.	Funnel		2			1 hotel, 2 stores, 2 mills, and 5 barns. Very destructive.	135,000	J. F. Llewellyn, Mexico, Missouri; and John F. Boynton, Syracuse, New York.
Dundee, Indiana <sup>f</sup>	16	8:15 p. m.	Easterly	Funnel			2,640		Many		Dr. J. D. Ebert, Dundee, Indiana.
Alamo, Michigan <sup>g</sup>	16	1 p. m.	Easterly	Funnel			Narrow				C. C. Adams, Alamo, Michigan.
Diamondale, Michigan <sup>h</sup>	16	12:30 p. m.	ne.	Whirlwind.							Postmaster at Diamondale, Michigan.
Brady and Wakarusa, Michigan.	16	Noon	ne.						1 church, several barns and windmills.		Ed. Bromley, Detroit, and J. A. Russell, Centerville, Michigan.
Shepardville and Saint John, Michigan. <sup>i</sup>	16	About noon.	ne.	Funnel					2 houses, 1 school, 2 barns, and many smaller buildings.		W. J. Van Velsar, Shepardville, and Ed. Bromley, Detroit, Michigan.
Victor Township, Michigan <sup>j</sup>	16	About noon.	Easterly						Houses and barns wrecked.		Ed. Bromley, Detroit, Michigan.
Howell, Michigan <sup>k</sup>	16	1 p. m.	ne.	Funnel	1	Several			Buildings of every description destroyed.	Many thousands of dollars.	Ed. Bromley, Detroit, Michigan.
Brighton, Michigan	16	1 p. m.	ne.						1 church, 8 barns, and many smaller buildings.	\$5,000-\$6,000	Ed. Bromley, Detroit, Michigan.
Half mile northwest of Wakelee, Cassopolis, Barron Lake, Penn, and Marcellus, Michigan. <sup>l</sup>	16	10:30 a. m.	n. 30° e.	Funnel			660 to 1,320		Many		J. M. Hoisington, Marcellus, A. H. Williams, Wakelee, T. R. Barron and T. M. Winchell, Barron Lake, and Francis A. Zerby, Penn, Michigan.
Rice Creek, Michigan <sup>m</sup>	16	11:30 a. m.	ne.	Funnel			660 to 1,320		5 barns, 9 windmills, and a very large amount of timber.		John B. Vernor, Rice Creek, Michigan.
Brooklyn, Michigan <sup>n</sup>	16	About 1 p. m.	Easterly	Funnel					Cloud too high in air to cause much damage.		J. D. De Lameter, Brooklyn, Michigan.
Bath Mills, Michigan	16	About 1 p. m.	ne.						10 houses and a number of barns.		Henry Little, Kalamazoo, Michigan.
Joliet and 9 miles southeast of Plainfield, Illinois. <sup>o</sup>	18	7:15 p. m.	ne.	Funnel	None	Many	50 to 300		20 houses, 10 barns, 2 factories, 1 elevator, 1 school, and many smaller buildings.	75,000	Geo. B. Tilton, Aurora, Jas. W. Boggs, Plainfield, Wm. Osman, Joliet, Illinois; and Henry Little, Kalamazoo, Michigan.
Buffalo, Missouri	18	A. M.	ne.						Very destructive.		J. F. Llewellyn, Mexico, Missouri.
Sentinel Prairie, Missouri <sup>p</sup>	18	3:30 p. m.	ne.	Funnel			2,640 to 6,600				J. L. Thurman, Sentinel Prairie, Missouri.

<sup>a</sup> A large black cloud hanging very low and sweeping swiftly over the ground from sw. There was a low, ominous roar, growing louder and louder, a brief lull, and then increasing to the sound of a train of cars rushing through a tunnel.

<sup>b</sup> The cloud had a rising and falling motion and swayed from side to side. Several of the massive stone steps leading up to the church were hurled down to the ground and broken to pieces. A piece of iron casting was blown a distance of three hundred yards and embedded in the ground. In crossing Onancock Creek the cloud gathered up an immense quantity of water, which was thrown to the ground beyond the creek with such violence as to cut holes in the earth.

<sup>c</sup> The cloud was very angry looking, preceded by white clouds in front, some of the points of which were low enough to touch the tops of houses. The funnel cloud was too high in air to cause much danger.

<sup>d</sup> The clouds were observed in w. in rapid contortions, now rising to a considerable height, now descending to the earth. The funnel cloud was very narrow and jumped rapidly from side to side in a swaying motion, causing destruction wherever it touched. Its contortions resembled a greatly troubled sea, rolling and tumbling along. It was accompanied by a loud, roaring noise, like a train of cars; height, probably one hundred feet, and diameter fifty to seventy-five feet.

<sup>e</sup> Funnel cloud was light blue at top, and in front black and ominous, as it rose from the horizon. As it ascended it appeared to drag after it three clouds of similar shape and color. The cloud was accompanied by a loud, roaring noise.

<sup>f</sup> The cloud formed rapidly in the w., being made up from a collection of dark clouds which came from nw. and sw., brought to view about twenty minutes previously by an ordinary gale.

<sup>g</sup> The clouds had two narrow streamers or funnels of a very dark green color. It was accompanied by a loud, roaring noise, like a train of cars shaking the earth.

<sup>h</sup> The storm was of a twisting character, and went in narrow strips or small whirlwinds, destroying everything in its path.

<sup>i</sup> Light whirling, black clouds, accompanied by a great, roaring noise.

<sup>j</sup> The cloud was accompanied by a loud, roaring noise.

<sup>k</sup> The cloud resembled a huge wheel in the western sky and moved with wonderful rapidity.

<sup>l</sup> The cloud appeared like a great wheel revolving in the western sky.

<sup>m</sup> The cloud had a rising and falling motion and roared like a train of cars. The tornado current was evidently in the form of two cones with apexes united. The nearer the apex junction came to the earth the more destructive the tornado.

<sup>n</sup> The cloud seemed to be very low down and very ragged, and the sky had a dark, greenish tint.

<sup>o</sup> The upper margin of the cloud was very dark, with a multitude of little eddies working toward the centre.

<sup>p</sup> Two clouds from nw. and sw., accompanied by scudding clouds, moved rapidly toward each other. Lightning played freely on both sides of the rapidly approaching cloud. As the clouds met a huge, funnel-shaped cloud extended downward. The cloud acted like a balloon, bobbing up and down and swaying from side to side, but at the same time moving forward at a terrible rate of speed.

<sup>q</sup> At 3:20 p. m. a foamy, vapory, irregular cloud appeared in the sw. For a time it remained apparently stationary, then all at once the southern portion separated from the northern portion and moved eastward very rapidly. The cloud was whitish, tinted faintly with green and purple. In ten minutes it burst upon us in terrific force, destroying everything in its path.